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Assessing Boat Damage to Seagrass Bed Habitat in a Florida Park from a Bioeconomics Perspective

Richard M. Engeman[†], Janice A. Duquesnel[‡], Ernest M. Cowan[§], Henry T. Smith[§††], Stephanie A. Shwiff[†], and Melissa Karlin[§]

[†]National Wildlife Research Center
4101 LaPorte Avenue
Fort Collins, CO 80521-2154, U.S.A.
richard.m.engeman@aphis.usda.gov

[‡]Florida Park Service
Lignumvitae Key Botanical State Park
P.O. Box 1052
Islamorada, FL 33036, U.S.A.

[§]Florida Park Service
Florida Department of Environmental Protection
13798 SE Federal Highway
Hobe Sound, FL 33455, U.S.A.

[††]Florida Atlantic University
Wilkes Honors College
5353 Parkside Drive
Jupiter, FL 33458, U.S.A.

ABSTRACT

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Seagrass bed habitat is an important biotic community in decline worldwide. Boat damage has long been recognized for its negative impacts on shallow-water seagrass beds, with those along the Florida coast particularly vulnerable in the face of a large human population possessing a large number of boats. Boat scars to seagrass beds recover slowly, resulting in new damage that often outpaces recovery of existing damage. We examined the rate of accumulation of total area composed of boat scars from 1994 to 2005 at Lignumvitae Key Submerged Land Managed Area, an area containing approximately 3400 ha of seagrass beds. We found the total area of damage increased from 1994 to 1997 by an average of 27.1 ha/y and from 1997 to 2005 by an average of 10.8 ha/y. This most recent rate of damage increase represents an additional $1,523,819 annual loss in habitat value using cost figures based on costs from restoration attempts permitted by the Environmental Protection Agency. Severe groundings investigated by law enforcement officers showed increasing trends over time in the average amount and severity of damage. The size of the boat inflicting the damage was more closely related to the severity of damage than to the amount of damage. The most immediate and practical measures for preventing damage include increasing signage to warn boaters to avoid seagrass beds and increasing law enforcement staff. Signage is a relatively low-cost, long-term investment that becomes cost-effective even if only 0.03 ha of seagrass bed damage is averted over the life of the signs. Each patrol staff member added becomes cost-effective even if only 0.42 ha of damage is averted annually. Holding the total area of damage constant for 1 year (new damage = recovery) would represent a benefit–cost ratio of 25.71 if accomplished with only one additional law enforcement officer.

ADDITIONAL INDEX WORDS: *Benefit–cost ratio, damage estimation, habitat valuation, habitat restoration, wetland.*

INTRODUCTION

Coastal seagrass beds have been declining throughout the world for a variety of reasons (Short and Wyllie-Echeverria, 1996). For many years, propeller scars from boats have been recognized for their significant negative impacts to seagrass beds (*e.g.,* Matthews, Lazar, and Hunt, 1991; Phillips, 1960; Woodburn *et al.,* 1957; Zieman, 1976). Shallow-water seagrass beds less than 2 m deep, such as those commonly found around Florida's coast, are especially susceptible to boat damage (Creed and Amado Filho, 1999). Moreover, seagrass beds in Florida are particularly likely to receive boat damage because more than 8 million people live along the Florida coast with over 750,000 registered vessels (Bell *et al.*, 2002). Furthermore, boat damage may interact synergistically with other factors, such as water clarity, to produce further declines (Orth and Moore, 1983; Preen, Lee Long, and Coles, 1995). Groundings create one or more injury types, including propeller scars, hull impressions, hull scars, blowholes (formed when the vessel uses its engines in an attempt to dislodge itself; Kirsch *et al.*, 2005), and berms (Sargent *et al.*, 1995). Depending on the extent of the damage (including the amount of topographic alteration), an injured seagrass bed may not recover on its own. Even so, natural recovery without implementing restoration techniques is slow, potentially taking more than 10 years (Sargent *et al.,* 1995; Zieman, 1976), and it can take up to 60 years for the seagrass bed to return to its climax *Thalassia* community (Fonseca *et al.*, 2004).

Seagrass bed productivity ranks among the highest of any natural biotic community (Zieman and Wetzel, 1980). In addition, seagrass beds have been recognized for the ecological function they provide to coastal ecosystems, thus bearing out the importance of habitat restoration (Fonseca *et al.*, 2002). Furthermore, seagrass blades remove suspended sediment from the water column (Fonseca, Kenworthy, and Thayer, 1998), promote good water quality (Fonseca, Kenworthy, and Thayer, 1998; Kenworthy and

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Schwarzschild, 1995), produce oxygen (Fonseca, 1990; Fonseca, Kenworthy, and Thayer, 1998), and provide food and shelter for numerous organisms (Ogden and Zieman, 1977). Seagrass beds release their production into estuarine/marine communities through both detrital food webs (Fonseca, 1990) and herbivorous food webs (Ogden and Zieman, 1977). Seagrasses stabilize marine sands and sediments, thereby allowing other floral and faunal components to colonize these areas (Fonseca, 1990; Kenworthy and Schwarzschild, 1995). Seagrass habitat also is a significant ecological component for coral reef ecosystems offshore, with negative impacts to this habitat adversely impacting the coral reef habitat (Ogden and Zieman, 1977). Similarly, seagrass habitat is vital to the organisms that migrate among the marine tidal swamp, the seagrass beds, and the coral reef system on a seasonal or diurnal cycle (Ogden and Zieman, 1977).

Lignumvitae Key Submerged Land Managed Area (LKSLMA) is an important conservation area for seagrass bed habitat in Florida. Here, we analyze two sources of data to examine the amount and value of boat damage to seagrass bed habitat over time. We also consider the benefits and costs of the feasible field methods for protecting this habitat most probable for implementation.

METHODS

Study Area and Damage Measurements

LKSLMA encompasses the 4050 ha surrounding the islands of Lignumvitae Key Botanical State Park, Shell Key Preserve State Park, and Indian Key Historic State Park (Florida Department of Environmental Protection Staff, 2000). This submerged land mostly comprises marine grass bed habitat (~3400 ha) but also contains marine composite substrate and marine consolidated substrate on the shallow flats and marine unconsolidated substrate in the channels (Florida Department of Environmental Protection Staff, 2000; Florida Natural Areas Inventory Staff, 1990). Although the seagrass beds are off-limits to boating, groundings frequently occur.

Current methodology for measuring damage to seagrass beds includes aerial photographic documentation and quantitative measurements of damage at the boat groundings investigated by law enforcement officers. Photographs showing boat scars include both investigated and uninvestigated boat groundings. Aerial photography of LKSLMA was carried out in 1994, 1997, and 2005 through a grant from the Coastal Zone Management Program. The combined area of damage from all scars was measured from these aerial photographs for each year to provide status and trend data on the accumulation of boat scars.

Because seagrass beds are off-limits to boating, groundings in seagrass beds merit a law enforcement response. When possible, park ranger responses to grounded boats on LKSLMA allowed the immediate location and measurement of damage impacts at investigated grounding sites. The responding law enforcement officer recorded the global positioning system locations of grounding incidents and marked sites with at least one polyvinyl chloride (PVC) stake at the end of the damage (usually the stern of the grounded vessel). The damage measured consisted of alteration to the substrate and cutting of seagrass rhizomes by the vessel or the propeller but not areas where only the seagrass blades were cut above the surface of the substrate.

A measuring tape attached to the PVC stake was used to measure the length of the propeller scar. Underwater photographs were taken of seagrass bed injuries associated with the grounding event, including blowholes, propeller scars, berms, and vessel impressions. If more than one injury type was observed for a grounding incident, then each was measured separately. Width of the scar was measured at specified increments, every 3 m, 6 m, or 15 m, depending upon the total length of the scar. Scars up to 76 m had width measured every 3 m. Scars between 76 m and 152 m had width measured every 6 m. Scars longer than 152 m had width measured every 15 m. Length, width, and depth were measured separately for blowholes, berms, and vessel impressions and were subtracted from the total length of the propeller scar so that no duplicate measurements were recorded for the different injuries. Damage of significant depth (≥12 cm) was recorded to assess whether topographic restoration would be necessary for seagrass restoration, because seagrass rhizomes cannot grow vertically if the topographic difference is greater than 20 cm (Kenworthy *et al.,* 2002). In such cases, if topographic restoration is not implemented, the seagrass injury will not recover and erosion may increase the injury size. Floral and faunal species diversity and abundance were surveyed in the surrounding seagrass flat to provide comparable information on the species lost to the injury. Coral species, including ivory tube coral (*Oculina* spp.), golfball coral *(Favia fragum),* finger coral *(Porites porites* and *P. furcata),* and rose coral *(Manicina areolata)* were recorded, but they were not part of cost calculation guidelines, making economic estimates of damage conservative. Average width was calculated for the propeller scar and other injury types, if applicable, and a total injury area was calculated for each injury type at each damage site.

Seagrass Habitat Valuations

Credible valuation of special habitats is not straightforward. Special habitats such as wetlands have limited market value, and when selectively protected, the market value diminishes further (King, 1998). This is especially true for seagrass beds since they cannot be developed. Nevertheless, multiple approaches can be applied for valuing seagrass habitat. The use of contingent valuation surveys is a common economic procedure, but for special habitats it tends to provide abstract appraisals of habitat value (King, 1998) and rarely forms the basis for environmental policy decisions (Adamowicz, 2004). One defensible, logical, and applicable valuation for damaged habitat is to use expenditure data for permitted mitigation projects. Such data represent an empirical demonstration of willingness-to-pay value and are most generally available for wetland habitats. United States dollar amounts per unit area spent in efforts to restore the various wetland habitat types has been presented by King (1998). The numbers represent the U.S. dollar amounts that environmental regulators, and to a degree elected governments, have allowed permit applicants to spend in attempts to replace lost wetland services and values (King, 1998). Using these figures, adjusted for inflation, leads to credible habitat valuations (Engeman *et al.*, 2004a), and this usage has been successfully applied to other special, protected habitats in Florida (Engeman *et al.*, 2003, 2004, 2007). In particular, the willingness-to-pay value for restoration of aquatic bed was $111,111.11/ha (King, 1998). The 2005 value for this cost estimate after adjusting for a 3% annual rate of inflation (King, 1998; Zerbe and Dively, 1994) was $140,752.23/ha and was applied to the damage area measurements from the aerial photographs of the seagrass beds from 1994, 1997, and 2005.

Empirical damage valuation data were also available for the subset of scars from investigated boat groundings. Pinpointing fresh damage geographically and temporally is only practical when responding to a grounding incident. Most groundings are not reported and consequently are not investigated because boaters are able to free themselves. Boaters also are financially motivated to free themselves to avoid costly towing expenses and fines for their damage to the seagrass bed (described later). Thus, investigated groundings tend to be firmly lodged boats, which produce the most severe scars to the seagrass beds. Damage calculations used by LKSLMA biological staff are based on the valuations by Kruer *et al.* (1996), and range from $71.47/m^2 to $161.46/m^2 depending on the level of topographic restoration. For damage sites with minimal topographic alteration, the cost was $71.47/m^2. For damage sites that have topographic alteration from 0.15 to 1 m, the median cost was $116.47/m^2. The median cost from major injuries, such as blowholes, was $161.46/m^2. As with the costs derived from permitted expenditure, damage values used in the analyses of investigated seagrass scars were adjusted into 2005 dollars using a 3% annual rate of inflation. Data on investigated groundings were tabulated temporally according to the Florida state government fiscal year (July 1–June 30). We calculated correlations to examine trends over time for investigated groundings in mean area of damage per such grounding, mean assessed value of that damage, and mean boat size causing the damage.

Benefit–Cost Analyses of Management Options

Monroe County, where LKSLMA is located, has been identified as a high-priority county for investing resources to protect seagrass beds (Sargent *et al.*, 1995). Based on unit costs of damage, we conducted benefit–cost analyses (BCAs) for field methods associated with identified damage prevention approaches (Sargent *et al.*, 1995). First, the null option of avoiding further expenditures beyond the present would be to take no additional actions toward damage prevention than the measures carried out now. Second, a method that has been demonstrated to reduce damage to seagrass beds is to increase the number of marker signs informing boaters that entry to seagrass habitat is restricted (Ehringer, 2000). New signs cost approximately $192 per sign for materials and labor to install, and 21–23 additional signs would be needed to fully delineate the perimeter of off-limits areas, making it nearly impossible for boaters to not see the boundary. The additional signs represent a one-time cost of less than $4500 to purchase and install. Third, increasing law enforcement presence by adding patrol staff would help prevent boats from venturing into seagrass beds. The annual costs for a fulltime patrol position currently are $59,400 for salaries, benefits, and equipment.

Table 1. *Amount and value in 2005 dollars of all existing scars to seagrass beds at Lignumvitae Key Submerged Land Managed Area, Florida, in 1994, 1997, and 2005.*

Year	Total Area of Damage (ha)	Average Annual Rate of Increase in Damaged Area (ha/y)	Total Value of Existing Damage
1994	36.02	NA	$5,069,895
1997	117.36	27.1	$16,518,682
2005	203.97	10.8	$28,709,232

We applied a benefit–cost model to estimate in monetary terms the level of damage reduction at which each field method becomes cost-effective. The BCAs follow the framework outlined in Boardman *et al.* (1996), Loomis (1993), Loomis and Walsh (1997), Nas (1996), and Zerbe and Dively (1994). Reduction of damaged seagrass habitat is seen as a benefit. In other words, if a management action could reduce the amount of seagrass habitat lost to boat damage, then the benefit of that management effort is the monetary value of that amount of habitat *versus* the costs of the effort. The BCAs involved estimating the benefit–cost ratio (BCR) of the monetary value of the benefits, measured as the value of different levels of reduction in area of seagrass beds suffering boat damage *versus* the cost of the field methods used to achieve the damage reduction. BCAs used the seagrass valuation figure based on restoration attempts permitted by the Environmental Protection Agency (EPA) ($140,752/ha), because this represents an average valuation for seagrass bed habitat.

RESULTS

Aerial Photography Damage Measures

The rate of accumulation of damage to the LKSLMA seagrass beds from 1994–2005 exceeded the rate of healing, producing a steady increase in the total area damaged (Table 1). The average annual rate of increase in damaged area was 27.1 additional hectares per year of damage from 1994 to 1997 and was 10.8 additional hectares per year from 1997 to 2005. The net amount of damage increased substantially during each period. The total value of damage in 1994, grown to present dollars (2005), was $5,069,895, which increased by an average of $3,816,262/y until 1997, when damage was valued at $16,518,682 (Table 1). The average increase in value of accumulated existing damage per year was $1,523,819/y from 1997 to 2005, when total damage was valued at $28,709,232 (Table 1).

Investigated Groundings Damage Measures

The total amount of damage in LKSLMA from only the investigated boat groundings for Florida state fiscal years

Table 2. *Average measures from boat groundings investigated by law enforcement officers at Lignumvitae Key Submerged Land Managed Area from 1998 to 2005.*

Fiscal Year (July 1–June 30)	Number of Groundings Investigated	Total Area Damaged (ha)	Mean Area Damaged (ha)	Total Damage Value	Mean Damage Value	Mean Size Damaging Vessel (m)
1998	4	0.0149	0.0037	$11,297	$2824	7.92
1999	14	0.1253	0.0089	$89,340	$6381	7.96
2000	13	0.0837	0.0064	$74,218	$5709	9.30
2001	12	0.1008	0.0086	$70,603	$5884	8.44
2002	21	0.2193	0.0104	$163,886	$7804	9.63
2003	19	0.2347	0.0124	$224,008	$11,790	9.33
2004	25	0.2830	0.0115	$164,881	$6595	8.47
2005	6	0.0518	0.0086	$49,818	$8303	10.79

1998 to 2005 (Table 2) was 1.05 ha, or 0.03% of the total 3400 ha of seagrass habitat within the protected submerged land. The assessment amount from this seemingly small damage area was $1,063,169.30 (adjusted to 2005 dollars). The severity of damage from investigated groundings is indicated by comparison to estimates for the same area of damage using the cost per hectare derived from the EPA-permitted mitigation data. This results in a value of $147,790, 13.9% of the preceding assessment. Over the years of this study, the mean amount of damage at investigated groundings, the value of the associated damage, and the mean sizes of the boats causing the damage all showed increasing trends ($r = 0.70$, 0.68, and 0.72, respectively). As would be expected, the mean amount of damage was correlated with the mean value of the damage ($r = 0.83$). The mean amount of damage did not relate particularly well to the mean size of boat causing damage ($r = 0.27$), although the mean boat size showed a stronger relation to mean value of damage ($r = 0.57$), indicating that boat size relates to severity of damage better than to area of damage.

Benefits and Costs for Field Methods to Mitigate Damage

Prior to analyzing BCRs for in-field actions to reduce damage, we first define damage reduction. For the last 8 years of the study, the net area of damage increased by 10.8 ha/y on average. Therefore, a rate of increase for net area of damage less than 10.8 ha/y is viewed as a damage reduction equal to its difference from 10.8 ha for a given year. Additional signs represent a long-term capital investment of less than $4500. This amount is equivalent to the value of 0.03 ha of lost habitat using the more conservative EPA mitigation valuation figure. Thus, the breakeven point for cost-efficacy of the additional signage requires them to produce only a cumulative reduction in damage of 0.03 ha over the life of the signs (reduce the net increase in damage by 0.03 ha). One full-time equivalent patrol staff position is annually equal to the value of 0.42 ha of seagrass bed damage. At current damage rates, each additional patrol staff achieves cost-efficacy for every 0.42 ha less than the 10.8 ha that net damage area increases each year. If, for example, the addition of two patrol officers holds accumulated damage constant for 1 year, then they would have reduced damage accumulation by 10.8 ha, producing an impressive BCR of 12.9 (Table 3).

Table 3. *Benefit-cost ratios for the addition of law enforcement patrol staff based on reductions in accrual of boat damage to seagrass beds, with seagrass habitat value derived from costs of EPA-permitted restoration efforts. The row with boldface numbers indicates the damage reduction level at which accumulation of damage area is zero.*

Damage Reduction (ha)	Additional Patrol Staff		
	1	2	3
1	2.38	1.19	0.79
2	4.76	2.38	1.59
3	7.14	3.57	2.38
4	9.52	4.76	3.18
5	11.91	5.95	3.97
10	23.81	11.91	7.94
10.8	**25.71**	**12.86**	**8.57**
15	35.72	17.86	11.91
20	47.62	23.81	15.88

DISCUSSION

From a broader perspective, our valuations and analyses of boat damage to LKSLMA can be considered conservative. Seagrass beds also provide an important economic function in light of their role as a source of food and shelter for many commercially and recreationally important species of fish, shrimp, and lobster (Fonseca, 1990; Fonseca, Kenworthy, and Thayer, 1998; Nelson, 1992; Zieman, 1982). A less tangible measurement of their importance is their economic value to offshore coral reefs in regards to recreational visitation to those reefs for snorkeling, diving, and fishing. Furthermore, the Florida Fish and Wildlife Conservation Commission acknowledges the economic value of seagrass habitat with relation to the fishing industry by conducting surveys of fish catches and fishing activity every year. For example, in 2002, seagrass communities in Monroe County alone (where LKSLMA is located) supported an estimated harvest of approximately $32.8 million for shrimp (*Penaeus* spp.), stone crab (*Menippe mercenaria*), Florida spiny lobster (*Panulirus argus*), yellowtail snapper (*Ocyurus chrysurus*), gray snapper (*Lutjanus griseus*) and blue crab (*Callinectes sapidus*) (Florida Fish and Wildlife Conservation Commission Staff, 2002).

The metrics for success in protection and conservation of vulnerable habitats is measured by the improvement in ecological variables. To effectively evaluate the returns on conservation efforts, the rewards from the expenditures must be in the same metric as the expenditures. The ability to monetarily value the habitat resource provides an effectual tool for evaluating conservation approaches. Funding is finite for recovery and conservation of habitats and must be carefully applied to maximize the positive impact on the protected resource. Analytical examination of the economics of management actions for habitat enhancement can provide managers with a logical working basis for selecting and implementing cost-effective conservation methodologies.

The best near-future estimate, if no additional management actions are taken to slow damage accumulation in LKSLMA, would be for total damage to increase by about 10.8 ha/y. The economic interpretation of this damage represents a further annual loss of habitat valued at $1,523,819/y. Given the benefit–cost performance of the damage prevention measures, we have to ask ourselves, How can we not afford to implement further protection measures to protect seagrass beds from boat damage?

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